Review of proposed amendments to Water Quality Control Plan for California Ocean Waters to address desalination facility intakes, brine discharges, and to incorporate other non-substantive changes

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Conclusion 1 A receiving water salinity limit of 2 ppt above natural background salinity is protective of marine communities and beneficial uses.

I am not a biologist, but the value of 2 ppt does seem consistent with available toxicological studies. Moreover, an excess salinity of 2 ppt salinity (dilution of roughly 20) is certainly achievable if there is minimal far field build-up. See Conclusion 4 below. *Thus I am generally supportive of the conclusion.*

Studies such as Phillips et al. (2012) typically report tests with fixed duration exposures (e.g., 48, 72 hours). Yet these durations may not match the exposures experienced in the field. Presumably some motile organisms would avoid the near field plume or crawl/swim through it, thus experiencing shorter term exposures. On the other hand, stationary biota, such as benthic infauna, could experience longer durations of elevated salinity, especially if an outfall is located in a poorly flushed area where the back-ground build up could extend over a considerable distance. Ideally at least some tests with time-varying exposure should be conducted. This is similar to other situations with time-varying pollutant exposures such as waste heat (temperature) from power plants, for which a substantial body of literature exists.

Phillips and 7 others (2012). "Hyper-Salinity Toxicity Thresholds for Nine California Ocean Plan Toxicity Test Protocols." U.C., Davis, Department of Environmental Toxicology. Report prepared for California State Water Resources Control Board, Agreement Number 11-133-250.

Conclusion 2 A subsurface seawater intake will minimize impingement and entrainment of marine life.

Missimer et al. (2013) discusses various types of subsurface intakes (vertical wells, angle wells, horizontal wells, radial wells, and seabed and beach galleries). The zones of influence of all systems as they intersect the seabed are much larger than the corresponding dimension of a surface intake, implying much lower velocities, meaning impingement is avoided. Also, the typical pore size of seabed sediments is small enough to avoid entrainment of fish larvae. *So I support this conclusion.*

Other potential advantages of subsurface intakes are cited, including improved raw water quality, reduced chemical usage, reduced energy costs (hence GHG emissions) and reduced overall cost to consumers (their higher capital costs are more than offset by lower operational costs). There are a number of operational SWRO plants using surface intakes, but not too many big ones. Clearly some sites are better than others, hydro-geologically speaking, but it also seems that designers are being cautious. Also, many of the examples come from the Middle East, where land is more available than in more congested California.

Missimer, T.M., Ghaffour, N. Dehwah, A.H.A. Rachman, R. Maliva, R.G. and Amy, G. (2013). "Subsurface intakes for seawater reverse osmosis facilities: Capacity limitation, water quality improvement, and economics" *Desalination* 322: 37-51.

Conclusion 3: A 0.5, 0.75 or 1.0 mm, or other slot sized screens installed on surface water intake pipes reduces entrainment.

I am not a biologist, but the available studies do seem to indicate that fine mesh screens do protect against larval entrainment. *So I generally support this conclusion*. But I would defer to others as to the optimal mesh size, if indeed there is a single optimum. The critical size depends on the larval size which is a function of the species, site, season and year. While changing screens on a seasonal or annual basis would seem burdensome, it could be appropriate to choose a unique size for a given station.

Most of the entrainment research has been done for electric power plants which experience similar problems of entrainment, but on a larger scale. One way to reduce entrainment at power plants is to minimize intake flow rates (e.g., through variable frequency pumps or by shutting down units for scheduled maintenance) during critical windows of time when small larvae are most abundant. Depending on the seasonal demands for freshwater, perhaps similar approaches could be used at desalination plants.

Conclusion 4: Multiport diffusers and commingling brine with other effluents can dilute brine discharge and provide protection of aquatic life.

Use of multiport diffusers and co-mingling of reject brine with other effluents can get near field dilution to within acceptable levels (~20). As shown below, so can pre-dilution directly with seawater (flow augmentation), as well as increasing discharge momentum. All approaches have some pros and cons that should be weighed.

For a single dense plume discharging from a flat bottom at an angle θ_o relative to horizontal, into quiescent receiving water, the terminal plume rise height h and the "near field" dilution S_n are given by

$$h = c_1(\theta_o)D_oF_o \quad (1a)$$

$$S_n = c_2(\theta_o)F_o \quad (2a)$$

where D_o is the effective orifice diameter (accounting for flow contraction if any), F_o is the discharge Froude number, $F_o = u_o/(\Delta_o D_o)^{0.5}$, u_o is the exit velocity $(4Q_o/\pi D_o^2)$, Q_o is the discharge flow rate, Δ_o is the reduced gravity $[g(\rho_o-\rho_a)/\rho_a]$, g is gravity, ρ_o and ρ_a are the densities of the discharged brine and the seawater, respectively, and c_1 and c_2 are empirical coefficients. For $\theta_o = 60^o$, Abbessi and Roberts (2014) give $c_1 = 2.25$ and $c_2 = 2.60$. The plume produces dilution through the entrainment of ambient water, so the dilution S_n in Eq. 2a implies an effective flow rate entering the near field of $Q = Q_oS_n$. If the reduced gravity of the discharge results solely from a single source, i.e., brine with an excess discharge concentration Δs_o, then $\Delta_o \sim \Delta s_o$. The near field concentrations above background (Δs and Δc), of salinity and of any other contaminant (e.g., product of corrosion, or anti-fouling agent) discharged with concentration Δc_o, are given by $\Delta c_o/\Delta c = \Delta s_o/\Delta s = Q/Q_o = S_n$. Eqns 1a,2b can also be written

$$h = c_1Q_o^{1/4}u_o^{3/4}/[(\pi/4)^{1/4}\Delta_o^{½}] \quad (1b)$$

$$S_n = c_2(\pi/4)^{1/4}u_o^{5/4}/[\Delta_o^{1/2}Q_o^{1/4}] \quad (2b)$$

The above equations are for a single jet discharging just the brine from a desalination plant. The accompanying sketch depicts an arrangement where the discharged flow can be pre-diluted with either: i) seawater, ii) treated wastewater effluent, and/or iii) heated condenser cooling water from a power station, making a combined flow of RQ_o. The discharge is evenly distributed through N ports of a multiport diffuser making the flow per port equal to RQ_o/N. The reduced gravity of the combined flow is $[\Delta_o + (R\text{-}1)\Delta_p]/R$ where Δ_p is the reduced gravity of the pre-dilution flow, which is proportional to the pre-dilution excess salinity, i.e. $[g(\rho_p-\rho_a)/\rho_a] \sim \Delta s_p$, defined as positive for a dense flow. For example, if the pre-dilution comes from pure seawater $\Delta_p = \Delta s_p = 0$ while if it comes from treated wastewater effluent or heated condenser cooling water Δ_p and $\Delta s_p < 0$. Using Eqs 1b, 2b, the maximum plume height and the dilution are

$$h = c_1(\theta_o)Q_o^{1/4}R^{3/4}u_o^{3/4}/\{(\pi/4)^{¼}N^{¼}[\Delta_o+(R\text{-}1)\Delta_p]^{½}\} \quad (3a)$$

$$S_n = c_2(\theta_o)(\pi/4)^{1/4}N^{¼}R^{5/4}u_o^{5/4}/\{ Q_o^{1/4}[\Delta_o+(R\text{-}1)\Delta_p^{1/2}]\} \quad (3b)$$

Again, the total induced flow rate is $Q = S_nQ_o$. Thus mass balances for the near field excess salinity and concentration above ambient are given by $\Delta c = [\Delta c_o + (R\text{-}1)\Delta c_p]/ S_n$, and $\Delta s = [\Delta s_o + (R\text{-}1)\Delta s_p]/ S_n$. The "effective" dilutions for salinity and concentration, in turn, are

$$S_{ns}' = \Delta s_o/\Delta s = S_n\Delta s_o/[\Delta s_o + (R\text{-}1)\Delta s_p] \quad (4)$$

$$S_{nc}' = \Delta c_o/\Delta c = S_n\Delta c_o/[\Delta c_o + (R\text{-}1)\Delta c_p] \quad (5)$$

Eqs 3-5 are exercised in the accompanying table. Note that for a given problem Q_o and Δ_o are fixed, while θ_o, R, u_o, N and Δ_p are design variables. Case 1 starts with base case parameters that do not meet a target near field dilution of 20 either for excess salinity Δs or excess concentration Δc (last two columns of the table). The remaining cases show that dilution increases (and a target of 20 can be easily achieved) by using a multi-port diffuser (increasing N; Case 2), increasing discharge momentum (increasing u_o; Case 3), pre-diluting the brine with neutrally buoyant seawater (increasing R with $\Delta_p = 0$; Case 4), and pre-diluting (co-mingling) the brine with relatively buoyant treated wastewater or heated water (increasing R and making $\Delta_p < 0$; Case 5).

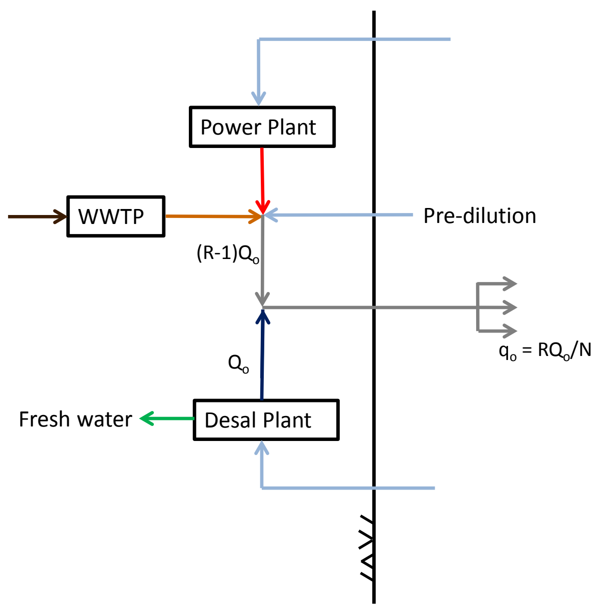
So all of these options can provide improved dilution. On the negative side, increasing u_o and R may require deeper water depth or shallower discharge angle to avoid plume surfacing, while increasing N allows discharge in shallower water. These are capital cost issues. And increasing either u_o or R requires more pumping energy, an operating cost issue. Environmentally, increasing R causes more water to be withdrawn at the intake with potential impacts due to impingement and entrainment, as well as impacts on the discharge side due to turbulent shear. Increasing u_o by itself could also increase turbulent shear. But if you can use another effluent (i.e., treated wastewater or condenser cooling water) for pre-dilution, then you have already suffered the impacts with sourcing and using that water, and if you are going to discharge the other effluent to the ocean anyway, you might as well let it improve your dilution. In the case of treated wastewater, however, an evaluation should be made as to whether commingling is a more valuable use than re-use (direct or indirect).

The improved dilution from co-mingling comes from both increasing R and decreasing the reduced gravity. In the case of brine, the "effective dilution" is increased further because the pre-dilution flow has negative excess salinity. This is reflected in the higher value of $S_{ns}' = \Delta_{so}/\Delta_s$ representing the reduction in salinity, relative to $S_{nc}' = \Delta_{co}/\Delta_c$ representing the reduction in concentration. Indeed, if $[\Delta_o + (R-1)\Delta_p] = 0$, the effluent would be neutrally buoyant and the effective brine dilution would be infinite (Eq 4), given sufficient water depth. And if $[\Delta_o + (R-1)\Delta_p] < 0$ the effluent would be positively buoyant. A separate dilution equation would need to be applied because the diluted effluent would float on the ocean surface, rather than fall to the seafloor. Because ambient velocities are generally higher on the surface than on the bottom, such a plume is more easily flushed in the far field, resulting in less brine build up. On the other hand, an aesthetic drawback is that the plume would be visible.

To summarize, I certainly support the conclusion that diffusers and co-mingling can provide good near field dilution. Flow augmentation can also be used, but is somewhat less effective, and simply adjusting the exit velocity may also work. Because there are multiple environmental impacts to be minimized (intake entrainment/impingement, near and far field concentrations of brine and other discharged pollutants, plus turbulent shear) and some of these vary with site *(e.g., variation in water depth and flushing) I do not believe a single strategy for dilution can be recommended.*

Following are several related comments. Many different locations within the plume have been used to define dilution (e.g., minimum dilution at maximum height, impact point dilution, near field dilution). The near field dilution is the most appropriate because it pertains to concentrations after discharge-induced mixing terminates. It is also relatively easy to measure.

Roberts et al. (2012) suggests that evaluating dilution under quiescent ambient conditions (as above) is conservative, which is generally the case, but may not be true for a multi-port diffuser. Depending on diffuser orientation and port size, plumes from adjacent nozzles may interact. For example, Adams (1982) shows degradation in the performance of a "Tee" diffuser (manifold



Case	Q_o	Δ_o	N	u_o	R	Δ_p	h	S	D_o	F	$\Delta s_o/\Delta s$	$\Delta c_o/\Delta c$
	(m^3/s)	(m/s^2)		(m/s)		(m/s^2)	(m)		(m)			
1-base case	0.1	0.3	1	1.5	1	0	3.3	13.1	0.29	5.1	13.2	13.2
2-diffuser	0.1	0.3	6	1.47	1	0	2.1	20.1	0.12	7.7	20.1	20.1
3-momentum	0.1	0.3	1	2.1	1	0	4.3	20.1	0.25	7.7	20.1	20.1
4 pre-dil (SW)	0.1	0.3	1	1.5	1.4	0	4.3	20.1	0.34	5.5	20.1	20.1
5- pre-dil (TWE)	0.1	0.3	1	1.5	1.25	-0.3	4.5	20.1	0.33	6.2	26.8	20.1

oriented parallel to shore) and improvement in the performance of a "Staged" diffuser (manifold oriented offshore) as ambient current increases. These applications were for condenser cooling water, with discharge flow rate and momentum considerably higher than found in typical brine discharges, so the issue will not be as acute. Nonetheless there has been very little study of dense multi-port discharges in a current.

All of the above relates to near field mixing. Roberts et al. (2012) correctly notes that one needs a combined near and far field analysis. It does little good to obtain tremendous near field mixing if the discharge area is poorly flushed, as the discharge will simply mix with itself allowing concentrations to build up. While the literature is replete with analyses of near field mixing (e.g., formulae such as Eqs. 1-2), there have been fewer published analyses of far field mixing, combined with near field mixing, applied to brine discharges. A good example or two would help regulators/designers.

A simple way to combine the near and far fields is to first identify the far field, or background, concentration of water entrained in the near field (Adams, et al., 1981). The far field dilution can be defined as

$$S_f = (c_o-c_a)/(c_f-c_a) \qquad (6)$$

while the near field dilution is

$$S_n = (c_o-c_f)/(c_n-c_f) \qquad (7)$$

where c_a, c_f, c_n and c_o are concentration in the ambient receiving water, the far field, the near field and the discharge, respectively. Combining Eqs. (6 and 7)) yields an expression for the total dilution, $S_t = (c_o-c_a)/(c_n-c_a)$

$$1/S_t = 1/S_n + 1/S_f - 1/(S_nS_f) \;\sim= 1/S_n + 1/S_f \qquad (8)$$

Clearly, the total dilution is less than either the near or the far field dilution. If the two dilutions have different magnitudes, the smaller one controls total dilution. For example, a small far field dilution can limit the maximum total dilution no matter how effective the near field mixing is.

Abbessi, O, and Roberts, P.J.W. (2014), "Multiport diffusers for dense discharges", *J. Hydraulic Engrg*. 140(8).

Adams, E.E. (1982), "Dilution analysis for unidirectional diffusers". J. Hydr. Div. (ASCE) 108(HY3): 327-342.

Adams, E., Harleman, D. R. F., Jirka, G.H., and Stolzenbach, K.D., (1981) "Heat disposal in the water environment", R. M. Parsons Laboratory, Dept. of Civil Engineering, MIT.

Roberts, J.P. (Chair) and four others (2012). Management of Brine Discharges to Coastal Waters, Recommendations of a Science Advisory Panel, Report prepared by the Southern California Coastal Water Research Project, Costa Mesa, CA for the State Water Resources Control Board, Technical Report 694, March 2012.

Conclusion 5: The Area Production Forgone (APF) method using an Empirical Transport Model (ETM) can effectively calculate the mitigation area for a facility's intakes.

The Area Production Foregone (APF) method is used to determine (the area of) an appropriate project, such as wetland restoration, that would offset the entrainment losses caused by intake water at a power plant or desalination plant. This calculation relies on an Empirical Transport Model (ETM) to estimate the portion of a population lost to entrainment in comparison to the overall population in the water body affected by the cooling water intake (source water body, SWB). This is typically done using target species, with the results extrapolated to other species (Steinbeck, et al., 2007).

Clearly this is only approximate, because it is assumed that populations are uniform over the SWB, and that conditions are simple, e.g., closed (no current) or open (with uniform ambient current). Raimondi (2011) also discusses the impact on APF of statistical error and sample size. While measuring or calculating the rate of larval entrainment is relatively easy, determining where the entrained larvae come from is more difficult, and assuming the SWB is either still or flowing uniformly, is clearly approximate. A more accurate, though burdensome, approach would be to simulate the transport of representative larvae, including their advection, diffusion, and behavior (e.g., vertical migration, natural die-off) with a Lagrangian transport model driven by a 3D circulation field. Recognizing that this is not always feasible, approximate solutions are required and the APF/ETM is a reasonable approach. *Thus I am generally supportive of this conclusion.*

Raimondi, P. (2011) "Variation in entrainment impact estimations based on different measures of acceptable uncertainty". California Energy Commission report CEC-500-2011-020, August 2011.

Steinbeck, J., Hedgepeth, J., Raimondi, P., Cailliet, G. and Mayer, D. (2007), "Assessing power plant cooling water system impacts", California Energy Commission report CEC-700-2007-010.